A System for Preventing Runway Incursions

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Introduction

Runway incursions are a serious aviation safety hazard. The number of reported incursions rose from 186 in 1993 to 431 in 2000, an increase of 132 percent. The Federal Aviation Administration (FAA) has begun several initiatives to reduce the incursion rate including education, training, improved airfield infrastructure (markings, signs, and lighting), and improved procedures. These efforts may have contributed to the decrease in reported incursions in 2001 to 383.

The National Transportation Safety Board (NTSB) has listed runway incursions on its ten most wanted list of transportation safety improvements every year since the list began in 1990. The NTSB has also made a specific recommendation that the FAA require, at all airports with scheduled passenger service, a ground movement safety system that provides direct runway incursion warning capability to the flight crews (A-00-66).

The FAA has been developing a runway incursion alerting system for ATC since the early 1990s. Any alerts generated by this system would be relayed to flight crews by ATC via voice communications. Currently, there is no system available onboard aircraft to provide the flight crew with surface situational awareness information or timely alerts of potential runway conflicts.

The key to preventing runway incursions is to ensure that pilots know:

- Where they are located
- Where other traffic is located
- Where to go on the airport surface

In the event an incursion still occurs, the flight crew and ATC should be immediately alerted to the situation.

A Runway Incursion Prevention System (RIPS) has been developed by NASA to provide this information in all visibility conditions. RIPS integrates airborne and ground-based technologies, which include flight deck displays, incursion alerting algorithms, onboard position determination systems, airport surveillance systems, and controller-pilot data link communications, with a highly accurate airport geographic database. The system can prevent runway incursions by providing the pilot with (1) enhanced surface situational awareness to avoid blunders and (2) alerts of runway conflicts.

RIPS System Description

The RIPS research flight deck displays are generated using an airport geographic database and inputs from position determination subsystems (for both ownship and other traffic). The database is developed based on the requirements specified in RTCA DO-272, User Requirements for Aerodrome Mapping Information.

A Head-up Display (HUD) is used for monitoring during final approach and tactical guidance during roll-out, turn-off, and taxi. Symbology presented during landing is similar to that used by commercial HUD vendors and is implemented solely to show how this guidance can transition to surface guidance (Figure 1). During landing roll-out, deceleration guidance to a pilot-chosen exit is provided, along with centerline and runway edge symbology. During taxi, centerline and taxiway edge symbols are provided along with centerline tracking guidance to a pilot-chosen gate location (Figure 2). Non-conformal information depicting the taxiway centerline and aircraft gear location is shown to aid in turns. An additional capability during landing roll-out, is guidance to a hold-short point on the runway. The HUD functionality is provided to enable all weather capability while reducing the likelihood of runway incursion through improved position awareness.

An Electronic Moving Map (EMM) is displayed when selected by the pilot, or automatically at nose wheel touchdown and 80 knots. The EMM graphically depicts the airport layout, current ownship position, current positions of other traffic, and ATC instructions (Figure 3). Several zoom/scale levels are available to the pilot. ATC instructions are portrayed graphically and textually. Text messages are shown on a pop-up window that the pilot can remove if desired. Graphic depictions of ATC instructions include the approved route and hold-short locations. Finally, any runway intersection that is ahead of high-speed runway traffic is highlighted to warn pilots that the runway is occupied. The EMM is provided to enable all weather capability while reducing the likelihood of runway incursion by supplementing awareness of position, traffic, and routing constraints.

Route deviation and crossing hold alerts are also generated by RIPS. Route deviation alerts (audible) are generated if ownship leaves its assigned path during taxi. Crossing hold alerts (audible) are generated if ownship crosses a hold line when not cleared to do so by ATC. These alerts can be transmitted to ATC so that corrective action can be taken before blunders lead to incursions.

Ownship position must be very accurate (<2.2m for large airports) to enable both surveillance and guidance functions. During flight testing, a Local Area Augmentation System (LAAS) was used to obtain differential Global Positioning System (GPS) corrections. The LAAS position data was then blended with inertial navigation system (INS) data and used for ownship position determination.

Traffic position data can be obtained by various methods. Automatic Dependent Surveillance – Broadcast (ADS-B) is a method of broadcasting data between aircraft and/or surface vehicles directly, without the use of ground-based equipment. By utilizing ADS-B, RIPS can be autonomous. Traffic data can also be sent from a ground surveillance system using Traffic Information Services – Broadcast (TIS-B). A surveillance system can acquire traffic data in the airport terminal area from several sources (Airport Surface Detection Equipment (ASDE-3) radar, Airport Target Identification System (ATIDS), ADS-B, taxiway sensor technology, etc.) and fuse this information to provide seamless coverage of the airport surface. The traffic data provided by a surveillance system can include non-cooperative traffic (trucks, baggage carts, construction equipment, etc.).

Runway Incursion Alerting

RIPS monitors a runway for potential incursions anytime the ownship is to enter the runway, e.g. during final approach and landing, takeoff roll, and taxi crossing. If an incursion occurs, algorithms that run onboard the aircraft generate alerts that are provided to the flight crew (audible and graphical). The RIPS algorithms are currently designed to provide alerting only. Maneuver guidance for taking evasive action is not provided. These aircraft-generated alerts can also be data linked to ATC so the pilots and controllers have the same information.

Two different incursion detection algorithms have been developed. The Runway Safety Monitor (RSM) was developed for NASA by Lockheed Martin Corporation. PathProx was developed by Rannoch Corporation under a NASA Cooperative Research Agreement.

The RSM incursion detection algorithm takes a generic approach for generating incursion alerts and is not designed for specific incursion scenarios. The RSM monitors traffic that enters a three-dimensional virtual protection zone around a runway that is being used by the ownship. Incursion detection is based on the operational state of the ownship and traffic, as well as other criteria (separation and closure rate), to avoid false alerts. Identification, position, and altitude data is used to track the traffic in the protection zone. Velocity and heading information is calculated from position reports since, from flight test experience, these data are not always reliable. RSM generates Runway Conflict Alerts (RCA) which occur when an actual runway incursion is detected and evasive action is required to avoid a potential collision.

The PathProx detection algorithm works on the same general premise as the RSM, utilizing runway zones and tracking of traffic within that zone. However, PathProx issues alerts based not only on the states of ownship and traffic, but on criteria associated with specific scenarios. State is determined by the location relative to the runway, speed, track angle, and acceleration. PathProx is designed to handle over forty specific runway incursion scenarios and generates two types of alerts analogous to the Traffic Alert and Collision Avoidance System (TCAS) approach. A Runway Traffic Alert (RTA) cautions the flight crew of a potential incursion or an incursion where the conflict does not yet require evasive action. The crew can take evasive action, however, at their discretion. PathProx also generates RCAs when immediate evasive action is required.

Alerts generated by a ground-based system such as the Airport Movement Area Safety System (AMASS) can also be transmitted to aircraft for display to the flight crew. While this method assures that controllers and pilots have the same information, alerts shown in the flight deck will not be as timely due to transmission delays. Ground based alerting systems are optimized for controllers and, as was found during flight testing, these alerts are usually generated later than the onboard alerts, leaving less time for the fight crew to react.

The alerts are presented to the flight crew both visually (on the HUD and EMM) and audibly. An audible enunciation is made in the flight deck ("Runway Traffic, Runway Traffic" for a RTA and "Runway Conflict, Runway Conflict" for a RCA). The textual forms of these alerts are presented on both the HUD and the EMM. On the EMM, the traffic symbol representing the incurring aircraft/vehicle is enlarged, changes color (yellow for RTA and red for RCA), is highlighted by a target box, and includes a five second projection vector. In the event the incurring traffic is not displayed on the EMM at the current zoom level, a symbol is pegged on the edge of the EMM in the direction of the traffic. Additionally, the identification tags are highlighted and information is displayed beneath the EMM ownship symbol and on the HUD indicating the distance to the incurring traffic. A target box also highlights the incurring traffic on the HUD. Figure 4 shows the RIPS displays during a RCA.

Controller-Pilot Data Link Communications

A Controller-Communication and Situational Awareness Terminal (C-CAST) enables Controller-Pilot Data Link Communications (CPDLC) in the RIPS system. C-CAST, developed by the Ohio University Avionics Engineering Center and St. Cloud State (MN), is designed to provide improved situational awareness to ATC, in addition to its CPDLC communication capabilities. A controller is shown a graphic display of the airport, overlayed with real-time airport traffic and identification (Figure 5). All traffic is tagged with an identification block that includes call sign or tail number, aircraft type, and aircraft equipment code. The map display utilizes colored identification blocks to highlight special conditions, e.g., red indicates runway incursion alerts.

C-CAST receives traffic information, runway hold bar information, and ground generated runway incursion alerts from a ground-based surveillance system via a TCP/IP connection. Airborne generated alerts (runway incursion, route deviation, and crossing hold) can be downlinked to C-CAST via the CPDLC link (ICAO Aeronautical Telecommunications Network (ATN) type message transmitted via a VHF data link-Mode 2 (VDLM2) channel and transferred through a TCP/IP connection).

The C-CAST communications provide the necessary CPDLC messages for surface operations, including incursion alerts. The ICAO ATN standard does not include messages needed for surface operations. C-CAST implements an "extension" of the ATN message set by adding the necessary surface operations messages, e.g., taxi to runway, taxi to ramp, taxi to gate, hold short, and cross runway uplink messages. For RIPS, CPDLC uplink messages are displayed to the flight crew in a text format and also graphically on the EMM as previously described.

C-CAST is designed to minimize additional workload while maximizing heads-up time for tower controllers during the creation of CPDLC uplink messages through the use of voice recognition. The C-CAST voice recognition system is speaker independent; therefore, the controller is not required to train the system. C-CAST also has touch screen capability that can be used to create uplink messages.

CPDLC downlink messages may contain either communications or situational information. Communication downlinks are used to confirm controller uplinks. Situational downlinks include messages such as runway incursion alerts, taxi route deviations, crossing active holds, and landing notification.

System Testing

The RIPS concept has been evaluated during several piloted simulation studies and flight tests. The most recent flight test was conducted at the Dallas-Ft. Worth International Airport (DFW) in October 2000. The objectives of the testing were to assess and validate technology performance and to demonstrate the system in an operational environment. Both airborne and ground components were evaluated including:

- Airborne and ground-based incursion detection algorithms
- ADS-B and TIS-B for traffic data
- HUD and EMM display systems
- LAAS for ownship positioning
- CPDLC for digital transmission of ATC instructions via C-CAST

Several incursion scenarios were tested using NASA's Boeing 757 research aircraft and an equipped test van as the incurring vehicle. The scenarios tested included a combination of landings with taxi crossings and departures with taxi crossings. A total of 47 test runs were completed using four commercial B-757/B-767 captains as test subjects. In general, the onboard alerts were generated in a timely manner, allowing sufficient time to react to the potential conflict. Any missed or false alerts were the result of missing or erroneous traffic data from the TIS-B and/or ADS-B sources. The ground-generated alerts usually occurred later than the aircraft generated alerts, particularly for the departure scenarios. Missed alerts from the ground-based system were the result of the alerting criteria and scenario timing. The aircraft generated incursion alerts were received first by the C-CAST 80% of the time for the same incident. The VDLM2-based CPDLC channel provided an excellent conduit for the incursion messages.

Downlink messages were received with 99.8% reliability and with very little bandwidth impact (50-70 bps). All the subject pilots stated they felt safer with RIPS onboard.

Enhancements were made to RIPS based on the results of the DFW testing. A piloted simulation study was conducted in March 2002 to further investigate the enhanced RIPS (incursion detection algorithms and display systems) using operational and visibility conditions that were not available during the DFW flight testing. Sixteen commercial pilots participated as test subjects. The data analysis for this recently completed simulation study is underway.

Summary

RIPS testing has consistently demonstrated the potential to reduce or eliminate runway incursions. By providing supplemental guidance, surface situational awareness, and incursion alerts to both pilots and controllers, runway collisions can be prevented while also increasing the efficiency of airport surface operations.

The following points can summarize lessons learned with respect to the incursion detection function of RIPS:

- It is essential that reliable, timely, and accurate traffic data be available to enable optimum onboard incursion detection
- Uplink of AMASS-generated alerts is not recommended due to the latencies involved and AMASS controller-focused alert criteria
- Further work should concentrate on the requirements for traffic information reporting to support the detection function

Research must also be performed to determine the appropriate procedures to use between the flight crew and controllers when a system such as RIPS is implemented.

NASA is working with the FAA's SafeFlight 21 program and various avionics manufacturers to transfer the RIPS technology to the marketplace to make terminal area operations safer.

Figure 1

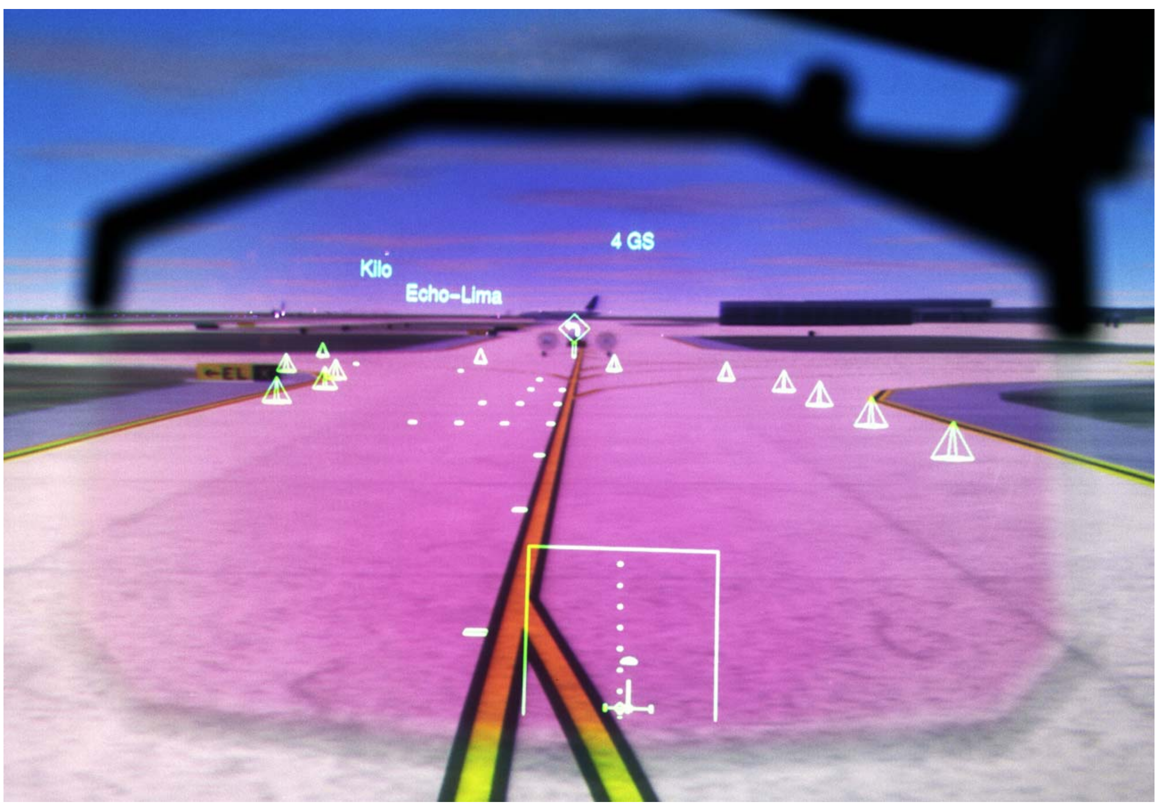


Figure 2

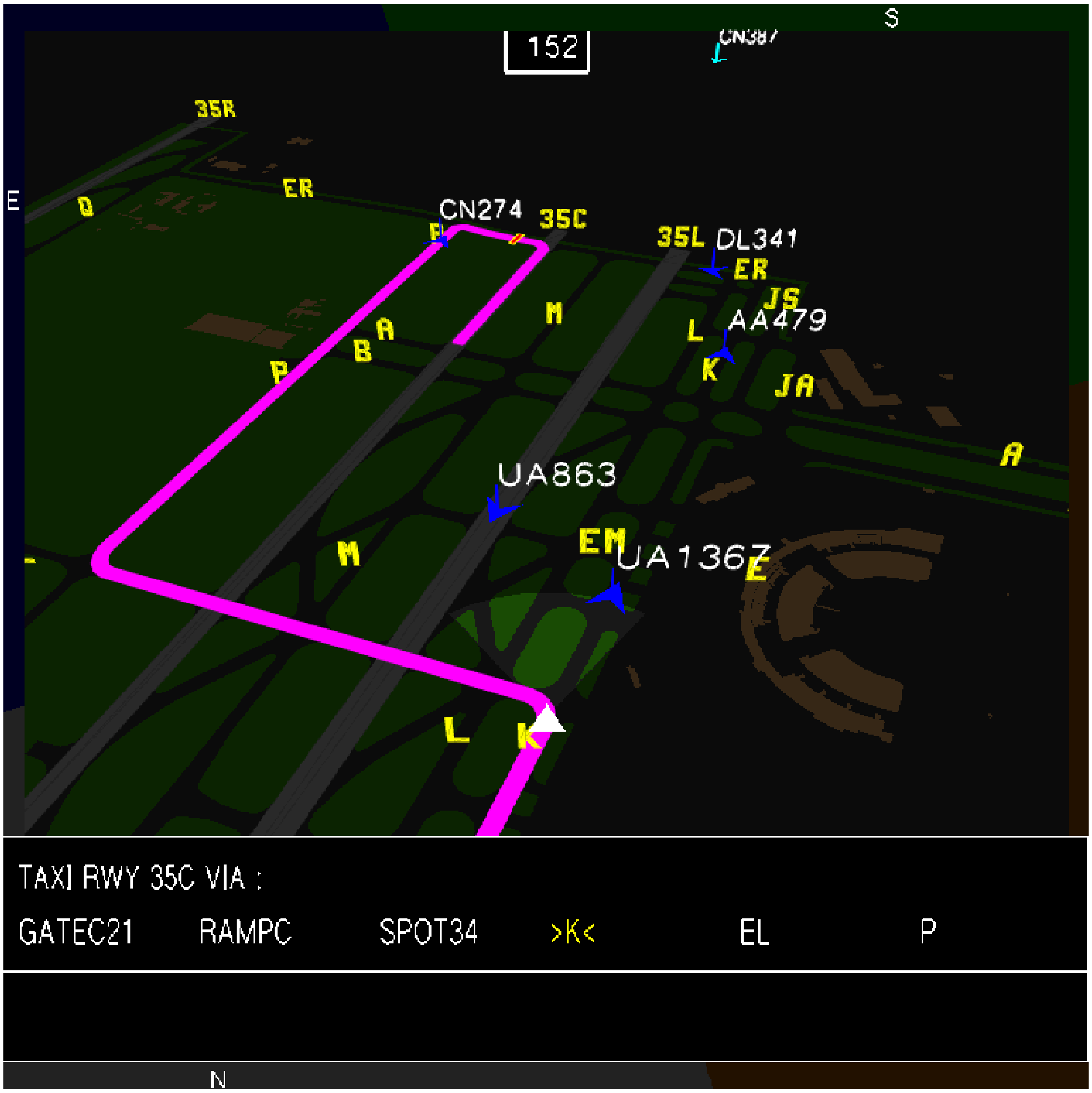


Figure 3

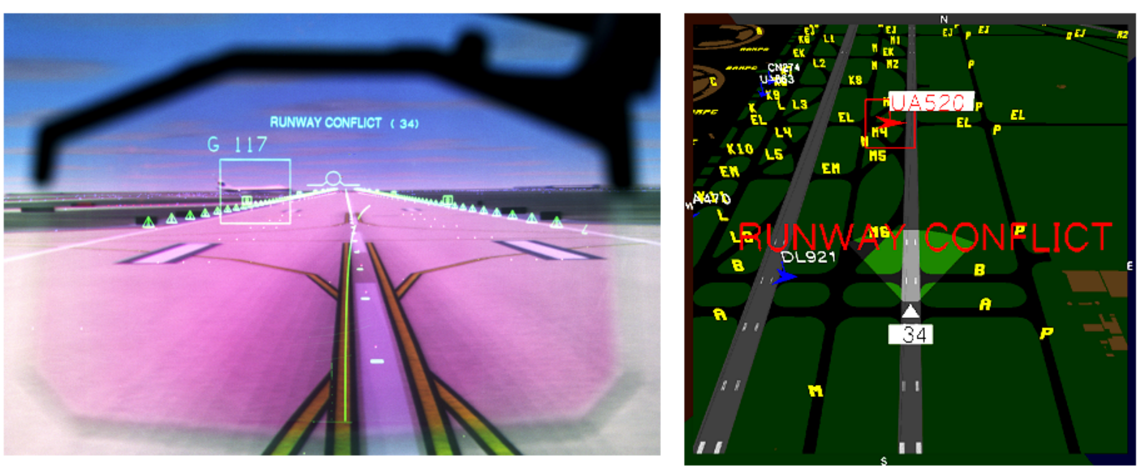
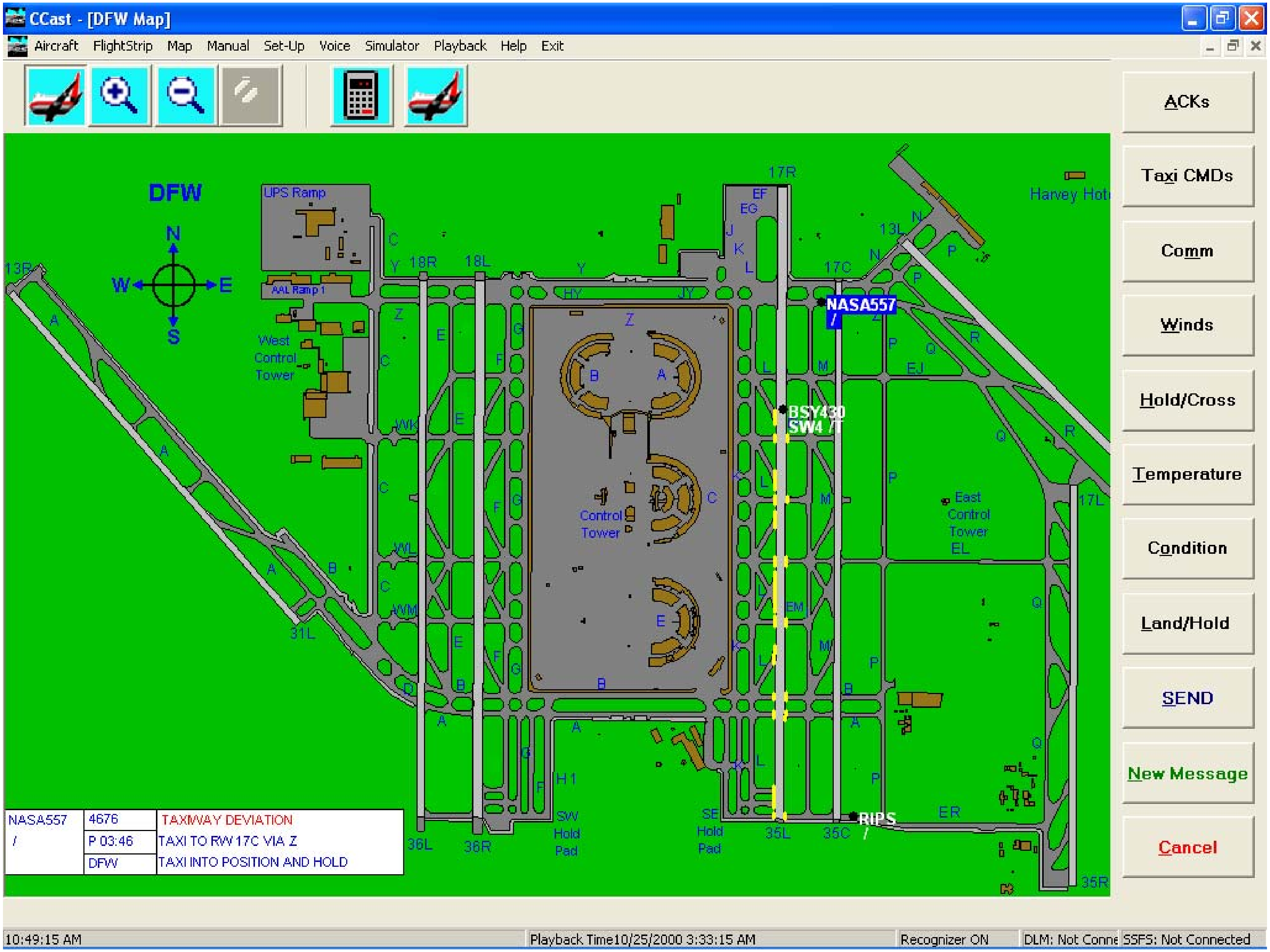


Figure 4



CCast - [DFW Map]
Aircraft FlightStrip Map Manual Set-Up Voice Simulator Playback Help Exit
ACKs
Taxi CMDs
Comm
Winds
Hold/Cross
Temperature
Condition
Land/Hold
SEND
New Message
Cancel
DFW
UPS Ramp
AAL Ramp 1
West Control Tower
Control Tower
East Control Tower
Harvey Hot
NASA557
BSY430
SW4
RIPS
SW Hold Pad
SE Hold Pad
17R
17C
17L
18R
18L
13L
13R
31L
36L
36R
35L
35C
35R
NASA557
4676
TAXIWAY DEVIATION
P 03:46
TAXI TO RW 17C VIA Z
DFW
TAXI INTO POSITION AND HOLD
10:49:15 AM
Playback Time10/25/2000 3:33:15 AM
Recognizer ON
DLM: Not Conne
SSFS: Not Connected

Figure 5